Application of LAS files in a Reservoir Characterization study to investigate Geologic Sequestration and Enhanced Oil Recovery in the East Canton oil field, Ohio

A Senior Thesis Submitted for Partial Fulfillment of the Requirements for The Degree of Bachelor of Science, Geological Sciences

Mickey Cronin
School of Earth Sciences
Autumn Quarter, 2008

S.D. McKenzie

Table of Contents

Abstract

With growing need for energy resources and mitigation of carbon dioxide emissions, there is increased interest in enhanced oil recovery (EOR) as a potential solution. Many oil fields with declining pressure and production still have the potential to produce millions of barrels of oil. Understanding oil-reservoir geology is important in determining how the formation will react to and sequester injected CO_2 as a method of EOR and mitigation. In this correlation study of reservoir stratigraphy within the producing interval of the East Canton field, geophysical wireline well logs and LAS file applications were used. This method allows for the gathering of large amounts of publically-available subsurface data to use in geologic interpretations. Many stratigraphic cross sections were created using LAS (Log ASCII Standard) applications; two representative cross sections are applied here. Through these cross sections, subtle and apparent changes in lithologic character, depositional environment, and continuity were observed for the producing interval, which is a series of complex sandstone lenses known as the "Clinton" sandstones. These cross sections and interpretations will add to an ongoing investigation by the Ohio Division of Geological Survey leading to the potential recovery of valuable energy resources along with the mitigation of an anthropogenic greenhouse gas.

Acknowledgments

I would like to thank Ron Riley for allowing me to be a part of this project and for the instruction given on all the components that enabled me to make this thesis possible. I would also like to recognize and thank everyone at the Ohio Geological survey that assisted me with their, time, input, creation of images, moral support, provision of data and tools, and a great internship that will serve me for years to come. Finally I would like to thank Garry McKenzie for his oversight on this project and support in order to get the job done.

Introduction

Since 1814 oil has been produced in Ohio. Commercial drilling became important in the state around the late 1850s to early 1860s (Janssens, 1977). With time, production decreases significantly within individual wells and oil fields to the point where it is no longer economically beneficial to produce from them. This is a challenge that faced many drillers and oil producing companies throughout the history of oil production in Ohio. Many techniques and processes have been developed and implemented over the years to meet this challenge. Early techniques included vacuum pumps, injection of compressed air and water flooding. The majority of these proved ultimately to be economically deficient, and ineffective in enhanced oil recovery (EOR). Methods of EOR are still being developed at present day and one that is on the forefront with the scientific community is the injection of CO2 into these oil-bearing geologic formations to repressurize the reservoirs, and mobilize unrecovered reserves to well bores stimulating production. This method of EOR presents a way to not only to meet the challenge of enhancing oil production, but as a way to help mitigate the emerging problem of CO2 emissions.

Enhanced Oil Recovery in Ohio

In 1995 the Ohio Department of Natural Resources Division of Geological Survey partnered with the Department of Energy (DOE) and put together a database based on an evaluation of the oil that remains in approximately eighty percent of the oil reservoirs in the Appalachian basin part of Ohio. This study was in contribution to the Department of Energy's study known as Tertiary Oil Recovery Information System project. The findings of this study showed that these reservoirs originally contained 5.7 billion barrels of stock tank oil. Of the 5.7 billion barrels a small 6.5 percent had been recovered for a total of 369 million barrels. By 1989 the state of Ohio could only attribute approximately one percent of its production by methods of Enhanced Oil Recovery (EOR). This is very low in comparison to bordering states such as Kentucky which produced 53.8 percent of its oil by EOR, Pennsylvania at 40.5 percent, and West Virginia at 25.9 percent (Blomberg, 1996).

Enhanced oil recovery in Ohio dates back as far as the 1800s. At that time they used vacuums or gas pumps to better retrieve oil from reservoirs. Gas and vacuum pumps were first employed in the Triumph pool of Pennsylvania in 1869 (Carl, 1890). The gas and vacuum pumping method ultimately yielded little in way of enhancing production and increased the cost of recovery as well (Lewis, 1917). As EOR advanced into the 20th century, injection of air and gas became common techniques to assist in repressurizing reservoirs. The Marietta compressed-air process was implemented in 1911 near Chesterhill, Ohio, and by 1970 the process had reached more than 90 properties and affected 4,000 wells in Ohio, West Virginia, Pennsylvania, Oklahoma, and California (Wolfe, 2005). The idea of this process was to replace the natural gas that was associated with the oil with compressed air. This is a simple and effective idea. The associated natural gas acts as a forcing agent on the oil to push it to the well bore, and once this natural gas is exhausted and pressure is negligible compressed air is pumped in to replace it (Lewis, 1917). Another process to assist in the recovery of oil reserves by secondary means is waterflooding. In 1939 the Ohio legislature legalized the use of waterflooding (O'Donnell, 1940). This is a technique that is also implemented when the pressure is too low to move the oil. Water is pumped into the reservoir via an injection well and moves through the formation sweeping some oil with it to the producing well bore. Once the oil and water is pumped out it is sent to a separating tank where the oil is separated and put into a holding tank to be sold (Cano Petroleum, 2008). The Chatham Oil field located in Medina County was chosen for EOR by Dymo Oil Corporation as a test pilot for waterflooding and its success led to more extensive development of EOR in the Chatham field during the following ten years. This EOR development led to a production of 9,365,000 barrels of oil and is considered the most successful waterflood for EOR in Ohio (Wolfe, 2005).

Carbon Sequestration

At present we are facing the immense challenge of mitigating one of the largest environmental problems of our time. One of the main contributors to this problem is the burning of fossil fuels. There are many natural producers of carbon dioxide and humans account for a small percentage over all, but this small percentage is proving to have a very large and very real effect. In the modern world we consume vast amounts of energy. Approximately 86% of this energy is produced by the burning of fossil fuels which also adds up to about 75% of anthropogenic carbon dioxide emissions (IPCC, 2001). During the 1990s many organizations and universities began to ramp up the studies on carbon capture and storage in geologic formations. This study involves the interests of the oil industry in enhanced oil recovery and in helping to sequester the carbon in the reservoirs they are producing from. Oil reservoirs provide a suitable place to store carbon dioxide. These reservoirs were originally and still are geologic traps that stored hydrocarbons in the form of crude oil and also have the potential with detailed research to store and seal carbon dioxide from the atmosphere.

Purpose of Study

This study began for me as an internship at the Ohio Division of Geological Survey (ODGS). Throughout the internship I have worked with geophysical wireline well logs to assist the survey in scanning, digitizing, and interpretation through cross-section of these logs. The work I have assisted with through the ODGS is a project being done in conjunction with the Baard Energy Company to construct the Ohio River Clean Fuels plant in Wellsville, Ohio. The operations are expected to commence in 2012. One of the objectives for the clean fuel plant is to figure out how and where it will sequester its waste CO_2. The main task that has been taken on by the ODGS is the assessment of CO_2 enhanced oil Recovery and Sequestration within the East Canton oil field. The East Canton oil field was chosen to be the best candidate for this project within a 50 mile radius of the building site for the Ohio River Clean Fuels Plant. The task of assessing sequestration and enhanced oil recovery by CO_2 involves a lot of subtasks; however my assistance was geared towards one of these subtasks. This subtask was to create cross sections from geophysical logs to assist in a reservoir characterization study. The objective of this subtask was to create a solid stratigraphic framework to help visualize any changes in reservoir stratigraphy and assist in creating a good model for geologic sequestration of CO_2 and enhanced oil recovery.

East Canton Oil Field

The East Canton oil field is located in northeastern Ohio and is made up either entirely or partially of eleven townships in Stark, Carroll, Harrison, and Tuscarawas counties. The limits of the oil field to present day have been pretty well defined. Although this particular oil field is one that is well established with plentiful reserves remaining to be recovered a detailed large scale, reservoir characterization has not been done. Reserves have been extracted from the East Canton field solely by means of primary recovery. Secondary and enhanced recoveries have not been attempted in the East Canton field. The focus of this study will include the wells that were drilled in Pike, Osnaburg, Sandy, Canton, and Marlboro townships in Stark County.

The East Canton Oil Field was discovered in 1953. Drilling would not begin until 1966 when development of the field grew quickly (Schrider et al., 1969) (McCormic, 1996). The discovery well was spawned off of the already gas producing Canton field into the East Canton area where commercial production began in Osnaburg Township, Stark County. A race for leases and permits to drill really took hold in 1967 with increased interest in the Pennsylvania-grade crude oil. From 1966 to the spring of 1968 the state issued around 600 permits to drill in the East Canton area (Knight, 1969). The productive zone covers an area of approximately 125,000 acres spread across the four counties listed above. The oil field is actually made up of many smaller pools and some large pools that may extend several hundreds of acres across the field (Sitler, 1969). In 1995 the East Canton field had 141 gas wells, 910 oil wells, 1,861 combination oil and gas wells, and 394 plugged and abandoned wells. These wells are separated by mandatory 40 acre spacing. The estimated cumulative oil production for the entire oil field as of 1995 was 86,489,200 Bbl (barrels). The estimated cumulative gas production for the field as of 1995 was 266,805 Mcf (TORIS, 1996). A study involving 30 wells in Rose Township, Carroll County showed that the gas to oil ratio averages 400 cubic feet per barrel of oil. This is with a maximum of 5,000 cubic feet per barrel of oil in the first 11 years of production. The drive mechanism for the East Canton field is solution gas

(McCormac et al., 1996). Solution gas drive is a relatively poor natural drive mechanism due to much of the oil remaining in the pore spaces once the pressure of the reservoir is depleted (Schrider et al., 1970). With a pressure depleted field such as the East Canton containing an estimated 51,867,800 Bbls of oil, it is a prime target for EOR and geologic sequestration of C02 (TORIS, 1996).

Previous Works

Marlboro Field Huff'n Puff

The following section highlights a case study done in the Marlboro field that is located at the northern-most tip of the East Canton field. This case study serves as an introduction to the work being done currently in the East Canton Oil field. The Huff-n-Puff process injects gas into a producing well known as (the "huff"). A dormant period known as "soak time" allows the gas to dissolve in the oil which enhances the solution gas drive mechanism, and the well is then brought back to production status (the "puff"). This field study was done between 1993 and 1995 and involved multiple injection and production cycles within four Marlboro field wells (Wonziak et al. 1997). Four wells the Dotson #3, #4, #5, and #6 in the northernmost tip of the East Canton field underwent two cycles of natural gas injection. The total production prior to the study was 79,000 barrels of oil and 115 MMCF of associated gas. In cycle one 35.0 MMCF of gas was injected over 12 months in cycles of 60-90 days per well, with an average injection pressure of 978 psig. The soak time between injections was 2-3 weeks. The oil production per well went from 1.4 barrels of oil per day to 5.7 barrels of oil per day (BOPD). A second cycle of injection (cycle two) on the same wells used 36.0 MMCF of gas over 12 months in cycles of 60-120 days per well at average injection pressures of 1,065 psig. In cycle two production went from 1.8 BOPD to 4.2 BOPD. Figure 5 taken from Wonziak and others (1997) provides additional details on the injections. The results from these tests wells assist in determining the potential response of other parts of the East Canton field.

DAVID A. WOZNIAK, JAMES L. WING, LEO A. SCHRIDER

Belden & Blake
Marlboro Field
Gas Storage/EOR Pilot

Well:	Dotson #3		Dotson #8		Dotson #5		Dotson #4	
	1st Cycle	2nd Cycle	1st Cycle	2nd Cycle	1st Cycle	2nd Cycle	1st Cycle	2nd Cycle
Max inj press, psi:	1,020	1,100	1,290	1,300	1,120	1,210	1,070	1,055
Avg inj press, psi:	900	995	1,120	1,220	965	1,080	925	965
Injected volume, mcf:	8,586	9,841	8,724	6,673	8,938	11,446	8,534	8,000
Max inj rate, mcfpd:	170	150	150	115	150	130	170	130
Avg inj rate, mcfpd:	112	145	102	85	109	85	155	80
Ult oil, Bbl (Primary):	32,200		14,000		30,500		23,600	

Note: As expected, higher injection pressures and lower injection rates were seen in the 2nd cycle.

Table 5: Marlboro Field - Natural Gas Huff-n-Puff Pilot Test Performance

Data and information pertaining to this study was taken from (Wonziak, Wing and Schrider, 1997).

Sequence Stratigraphy by Robert T. Ryder, 2004

Ryder put together a series of six cross sections that spanned parts of New York, Pennsylvania, Ohio, and West Virginia. The cross section that is taken in to consideration for the purposes of this paper is E-E´ (figure 2.), that is approximately 235 miles long, roughly normal to the depositional strike of the lower Silurian depositional system, and cuts through the East Canton Oil Field in Ohio. Within Ryder’s sequence stratigraphic framework he defines two distinct sequences which he labels sequence 1 and 3 with the intermediate sequence 2 undefined in this work (Ryder, 2004) (figures 1-3).

Sequence one is defined at its base by the top of the Queenston formation known as the Cherokee Unconformity and at the top by a second unconformity named 3T on E-E´. According to Ryder both unconformities were likely the result of a fall in eustatic sea level. Sequence one is composed of a transgressive systems tract and an overlying high stand systems tract. The transgressive systems tract is made up of the Medina sand and the Lower Cabot Head shale. The depositional environment for the Medina sand is described as shoreface with a basal braided fluvial component. The Cabot head shale portion contained in the transgressive systems tract is defined as mudstone and shale that terminate at a maximum flooding surface based on a high gamma ray log response. The High stand system tract component within this area is thought to be associated a westward prograding shoreface, barrier bar, or tidal delta deposit (Ryder, 2004) (figure 3).

Sequence three consists of a transgressive systems tract and an undefined systems tract. The sequence is defined at its base by unconformity 3t and at the top by what is being defined as a ravinement surface which is at the base of the unnamed limestone/dolomite unit (Overbey and Henniger, 1971). The interval of sequence 3 contains 50-100ft thick “Clinton” sandstones that are interpreted as fluvial channel deposits associated with the backfilling of paleovalleys during a rise in base level (Hettinger, 2001). The upper part of this sequence is a composite unit of shale, siltstone, mudstone, and thin sandstone which are interpreted as tidal flat deposits which is not explicitly stated, but possibly represents the undefined systems tract (Ryder, 2004) (figures 5, 6).

Methods and Procedures

Creation of LAS Files and Cross Sections

For this reservoir characterization study I created cross sections by utilizing and interpreting geophysical wireline well logs. These well logs contain a wealth of geologic information that spans the state. The types of well logs that I utilized for the purpose of this study include Gamma Ray, Neutron, and Bulk Density logs. These logs provide key information regarding lithologies, correlation, porosities, permeability, structure, and stratigraphy. To better utilize the well logs using computerized graphics, and application I converted the logs to a digital format. To accomplish this task I used a Neuralog™ brand scanner and digitizing software on the well logs in my study area. The Neuralog™ software is an autovectorizing application that creates a Log ASCII Standard file, or as it is known to users, LAS files.

The first step of LAS conversion of these well logs was getting the paper copies scanned onto a computer system. Once the log was scanned on to a computer it was then known as a raster image or TIFF file (Tagged Image File Format). The raster image and file that was created by scanning the paper log was then brought into a program known as Neuralog™. Neuralog™ was used to convert the TIFF file to the LAS format. LAS format is a text file (figures 14-15) that contains vector values for each curve that was digitized and well header information such as the drilling company, logging company, geographic position of the well, reference datum, and other information relative to the log that belongs to each respective well. Before the Neuralog™ technology was available these TIFF files were manually traced in graphical illustration application which produced vectorized images, but it did not provide usable coordinate data (Crangel, 2007). After the LAS file was created it was readily available to be viewed by the LAS viewer GeoGraphix Prizm™, which was utilized in this particular study. In the GeoGraphix Prizm™ viewer I was able to edit and check for consistencies between the paper copy and the digital copy. Through these checks one can create a template for each unique log. This was a necessary step for quality assurance due to variations of scaling and placement of curves. Each logging company has many standards that are unique and some that are similar in respect to each other; therefore this aspect deserved attention to insure the quality of the data is being presented. Once all the LAS files were imported into the program and templates were created they were readily available to be accessed and put into cross section by way of another feature in the GeoGraphix™ software (figures 14-15).

My cross sections and interpretations serve primarily as a stratigraphic correlation of the Clinton, or as known to drillers as the "Packer Shell" formation, throughout the area of study. This is the producing formation of the East Canton field. To do this I used mainly utilized the unique response of the Gamma Ray curve that is given off by this formation. Through this response I was able to pick out the top and bottom of the formation and make correlations along strike and dip throughout the entire study area (figures 5-6).

Gamma Ray, Neutron, and Density Curves

Gamma Ray: Gamma Ray logs measure the amount of natural radioactivity within formations. This tool measures radioactivity within formations similar to that of a

Geiger counter. Radioactive isotopes are the primary source of radiation being read from the gamma ray tool. These are isotopes such as thorium, potassium, and uranium. Since radioactive elements tend to accumulate in clays and shales the gamma ray curve would ultimately reflect the shale content of a formation. Therefore sandstone would typically give off a low gamma ray reading whereas shale would give off a relatively high reading when speaking of rock formations. Radioactive contaminants such as volcanic ash and granite wash may affect the gamma ray reading. Densities also need to be considered, because two formations that have similar radioactivity might read differently on a gamma ray curve based on their densities. A formation with lower density will typically give off a higher gamma ray reading. The units that are used to measure these readings are known as API units which stand for American Petroleum Institute units. These units create a standard for log comparisons within the industry. This scale was calibrated to 100 API units matching that of a typical Mid-continent Shale (Schlumberger, Log Interpretation Principles, 1969).

Neutron: The neutron is an atomic particle whose charge is neutral and mass is nearly identical to that of a hydrogen atom. Neutron logs are therefore useful in determining the amount of hydrogen that is present within a formation. This information can be used in the delineation of porous formations to ultimately determine the porosity of the formation. Shale might appear to have high porosity due to the fact that it has a certain amount of water trapped inside of it. This can be deceiving in terms of porosity due to the fact that shale has extremely low permeability and in turn low effective porosity. Shale free sandstone however produces a signal that is much more useful in terms of porosity. Units encountered in this study are counts per minute, counts per second, API, or percentages. Counts measure the amount of collisions between the neutrons derived from the tool and the hydrogen atoms within the rock formation. Counts or API units are ultimately converted to percentages which is the standard measurement for porosities (Schlumberger, Log Interpretation Principles, 1969).

Density: The density log measures the apparent density of the rock formation and is also useful tool in determining porosity. A tool that emits gamma ray particles into the formation is the way in which the density is ultimately measured. Gamma rays are shot into the formation which collides with electrons continuously through the formation with decreasing energy. This concept is known as Compton Scattering and it is thought to be directly related to the amount of electrons within a formation. So the detector on the tool is measuring the electron density of the formation which is correlative to the bulk density of the formation. Porosity may be determined by taking the difference between the known matrix density and the formation bulk density divided by the difference between the known matrix density and the formation bulk density. Based on returned density values lithologies can also be determined. Density coupled with the neutron readings can give a better estimate of lithologies and porosities at depth than either one alone (Schlumberger, Log Interpretation Principals, 1969).

Geology

Regional Structure

The East Canton oil field is located on the northwest edge of the Appalachian foreland basin. The “Clinton” sandstones are all homoclinal dipping beds that rest upon a monocline. Up dip from the East Canton oil field are the Stark-Summit, Canton, and Mineral City gas fields. In this area there is evidence of a broad gentle anticline that plunges from North to South (Sitler, 1969). The East Canton oil field “Clinton” sandstones have a east to southeast dip that averages less than one degree or according to Knight (1969) 50 ft/mi. The strike ranges from N 10 E to N 50 W (Schrider et al., 1969).

Regional Stratigraphy

The “Clinton” sandstone is Lower Silurian in age and well known to geologists and drillers across the state of Ohio. It was first coined as the Clinton sands when the formation was discovered in a gas producing well located in Lancaster Ohio in 1887. The name Clinton was applied because it was stratigraphically close to the Limestone that was named Clinton by Edward Orton (Orton, 1888). Applying the Clinton name to this sandstone was a misnomer according to Sitler and suggests that the name Clinton actually refers to a series of shales and limestone at the base of the Niagaran group that is Middle Silurian in age (Sitler, 1969). This unit is Lower Silurian, Llandoverian in age and lies between the Dayton formation known to drillers as the Packer Shell and the late Ordovician Queenston formation (Kleffner, 1985). The once thought gas producing limestone was actually a gas producing sandstone that was not part of the Clinton group, but part of the group underlying it known as the Cataract/Medina group. This case of mistaken identity is one that has stuck for over a century, and with the deeply rooted misnomer it will affectionately always be known to many as “Clinton Sand” (McCormic et al., 1996). The “Clinton” sandstones of Ohio correlate to the Tuscarora sandstone of West Virginia, the Grimsby sandstone of northwestern Pennsylvania, and the Medina group/Grimsby formation of western New York (Ryder and Zagorski, 2003) (figure 4).

The sandstones are divided by many into three different members known as the Stray Clinton, Red Clinton, and White Clinton Sandstones which are primarily driller's nomenclature. The Stray, Red, and White Clinton sandstones are correlated by many to the Thorold and Grimsby sandstones of New York, Pennsylvania, and Ontario. The basal unit of the Cataract/Medina group is known as the Medina Sandstone, and is correlated to the Whirlpool sandstones of the same states. In Ohio and Ontario the Clinton/Grimsby sandstones are interbedded with the Cabot Head shale. The lower Cabot Head shale is interbedded with the White Clinton. The Stray Clinton interbedds with the upper part of the Cabot Head shale and is known to drillers as the Stray Clinton due to its irregular distribution. The Red and White Clinton units derived their respective names by drillers due to their distinctive colors (Knight, 1969). Production has been most successful with the Red Clinton sand which has natural fracturing and porosity that is superior with respect to the other units (Sitler, 1969). Unconformably overlying the Stray Clinton is the unit known to drillers as the "Packer Shell" formation which is a series of impermeable limestones that serve as the cap rock to seal the "Clinton" reservoir from above. For the purposes of this study these limestone units will be referred to as the Dayton formation. There is also a well known unconformity below the "Clinton" known as the "Cherokee" unconformity that separates the "Clinton" and the underlying Queenston Shale unit (figure 4).

Depositional Environments

The Lower Silurian system at the time the "Clinton" sands were being deposited is modeled as a clastic wedge building in response to the Taconic orogeny. Deposition of large sandstone units such as those in Pennsylvania and West Virginia developed from basin subsidence creating accommodation space and a large supply of sediments to be weathered due to uplifted strata (Castle and Byrnes, 2005). The “Clinton” sandstone units are fluvial deltaic, estuarine, and near shore marine depositional units that display a sequence of sea level rise and fall. The unconformities on either side of the “Clinton” may be interpreted as a period of non-deposition due to a fall in eustatic sea level (Dennison and Head, 1975). The “Clinton” sandstone units show a variety of features that indicate the various depositional facies that are mentioned above such as massive to lenticular bedding, cross bedding, shale/sandstone interbedding, and fining upward sequences. These features have been observed in core and in gamma ray log responses (Ryder, 2004).

General Reservoir Characteristics

- Rock Character: Very fine to fine grained quartz sandstone, red to white/gray in color with varying amounts of silt content and shale interbeds, grains are generally well to moderately sorted, and grain shape is round to subround. *Secondary Mineralization:* Hematite, Calcite, gypsum, anhydrite and Halite (Ryder and Zagorski, 2003) (Knight, 1969) (figure 12). *Structures:* Parallel and cross laminations, ripple drift laminations, high energy bioturbation, and trace animal burrows (Knight, 1969), (figure 10).
- Porosity: 5 – 10% (Castle and Byrnes, 2005), (figures 11-12.)
- Permeability: Less than or equal to 0.1 millidarcy (Watts et al., 1970) (figures 11-12)

- Fracturing: Orientation of vertical to subvertical fractures are Northwest and Northeast with the Northeast trending fractures dominant. Fractures may be open or closed due to the formation of secondary minerals within the fractures (Ryder and Zagorski, 2003).
- Diagenesis: Local pressure solution of detrital grains, calcite cementation, silica cementation by syntaxial quartz overgrowth, dissolution of feldspar grains, authegenic feldspar overgrowths, and dissolution of calcite cement. (Ryder and Zagorski, 2003).

Trapping Mechanism

Traps are features of geologic formations either structural or stratigraphic that enable the formation to retain and accumulate hydrocarbons. The structural features of the “Clinton” sandstone reservoirs within the East Canton field are thought to be ineffective as trapping mechanisms (Knight, 1969). However, there are small scale anticline noses, faults, and terraces that have local control of entrapment of hydrocarbons and enhance well production within certain fields in northeastern Ohio (Ryder and Zagorski, 2003). According to Knight (1969), structure may account for the vertical segregation of oil and gas within individual reservoirs. Stratigraphic traps are proposed to be the mechanism responsible for hydrocarbon accumulation within the East Canton field. According to Ryder and Zagorski (2003) hydrocarbons that are trapped in the “Clinton” reservoirs only average about 15 ft. in thickness which suggests that the sealing capacity of the trapping facies is only slightly higher than that of the reservoir facies and leads to the thin column of accumulation along with an up dip leakage of oil. A variety of mechanisms are said to be responsible for these stratigraphic traps such as, changes in porosity, gas-water contacts, pinching out of sandstone beds, and diagenesis (Laughrey and Harper, 1986).

Interpretation of Data

Detailed cross sections within the East Canton oil field illustrating the Clinton sandstone interval are presented and discussed in this section (figures 2, 7 and 8). The Clinton interval is the primary unit being investigated for CO_2 sequestration and EOR for this field. The cross sections created for this project (figures 7, and 8) are not as detailed with some of the thinner sandstone lenses within the Grimsby sandstones such that Ryder depicts (figure 2), but beyond this aspect they are in agreement. In making the previous statement the sequence 1 and sequence 3 units and boundaries were incorporated into the cross sections created for this paper such as Ryder (2004) describes within his work.

The signatures of the logs show some subtle and apparent changes in depositional facies, lithologic character, and continuity of formation. The “Medina” sandstone unit is lowest sandstone unit within the Cataract group in cross section and the base of sequence one. The gamma-ray log signature of this unit displayed a fining upward signature that would indicate a fluvial component or possibly a braided fluvial system with a shoreface component which is proposed by Ryder (2004) and in agreement with Laughrey (1984), Middleton and others (1987), Castle (1998), and Hettinger (2001). The lower Cabot Head shale was picked based on a high gamma-ray response through the interval in which it is labeled. For the purposes of this thesis and in agreement with Ryder (2004), it is interpreted as offshore marine shale deposited at the height of a transgression event in deeper waters. The basal sandstones of the "Clinton" formation also known as the "White Clinton" represent the last units depicted in sequence one. These sandstones are interbedded with lower Cabot Head shale/mudstone and show a stacked pattern of lenticular beds due to thin symmetrical gamma ray curves that vary in thickness. This signature according to Ryder (2004) may be interpreted as retrogradational shoreface and tidal channel deposits in agreement with Hettinger (2001). The other signature that was observed in this interval was an upward decreasing gamma ray signature that according to Keltch (1985) represents a coarsening upward grain size in sandstones and a coastal barrier or offshore bar depositional facies.

Sequence 3 begins at unconformity 3T described in Ryder (2004), and at the base of the middle "Clinton"/Grimsby units colored straw yellow in Strike 2 and Dip 2 (figures 4-5). The log signatures that are observed within the cross sections Strike 2 and Dip 2 for this unit are increasing upward to blocky type gamma ray responses. These responses according to Kelch (1985) indicate distributary mouth bars, filling of delta channels, and braided stream deposits. This interpretation somewhat agrees with Hettinger (2001), which was adopted in Ryder (2004) of fluvial/tidal deposits caused by the backfilling of paleovalleys during a transgression. The upper boundary of this sequence is defined by the uppermost "Clinton"/Grimsby units that display variable signatures, and indicate shale and sandstone that varies a great deal laterally. These signatures agree with Ryder's (2004) interpretation of this unit as a composite of shale, siltstone and thin sandstones, and were interpreted as tidal flat deposits by Laughrey (1984) and Castle (1998).

Conclusion:

The East Canton oil field is a pressure- depleted, solution gas drive reservoir that has a significant amount of oil remaining in place to be recovered. Sequestering CO_2 and using it for EOR in depleted reservoirs like the East Canton “Clinton” reservoir is an important process to investigate with respect to reducing the emissions of these greenhouse gases. To help investigate and carry out large scale reservoir characterizations, the interpretation of geophysical wireline well log through LAS applications is a relatively easy and accessible way to gather and interpret large amounts of data for geologic reservoirs such as the “Clinton” sandstones. The data presented here in way of cross section and interpretation will add to a bank of knowledge that will help implement the joint effort that is underway between the Baard Energy Company and the Ohio Division of Geological Survey. If this project proves to be a successful one it could serve the globe in way of improved and efficient oil recoveries and in storage for anthropogenic CO_2 in fields similar to the East Canton oil field.

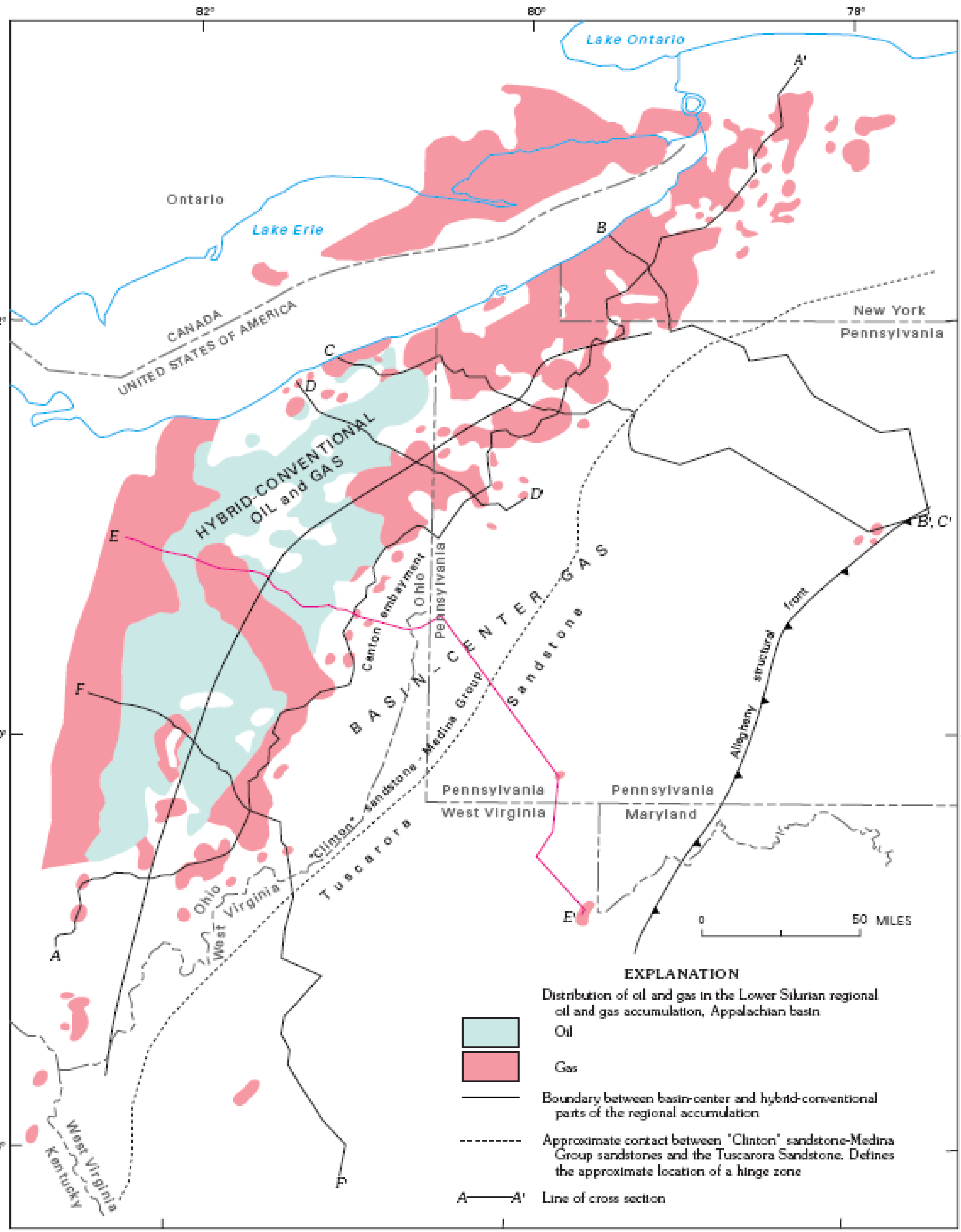
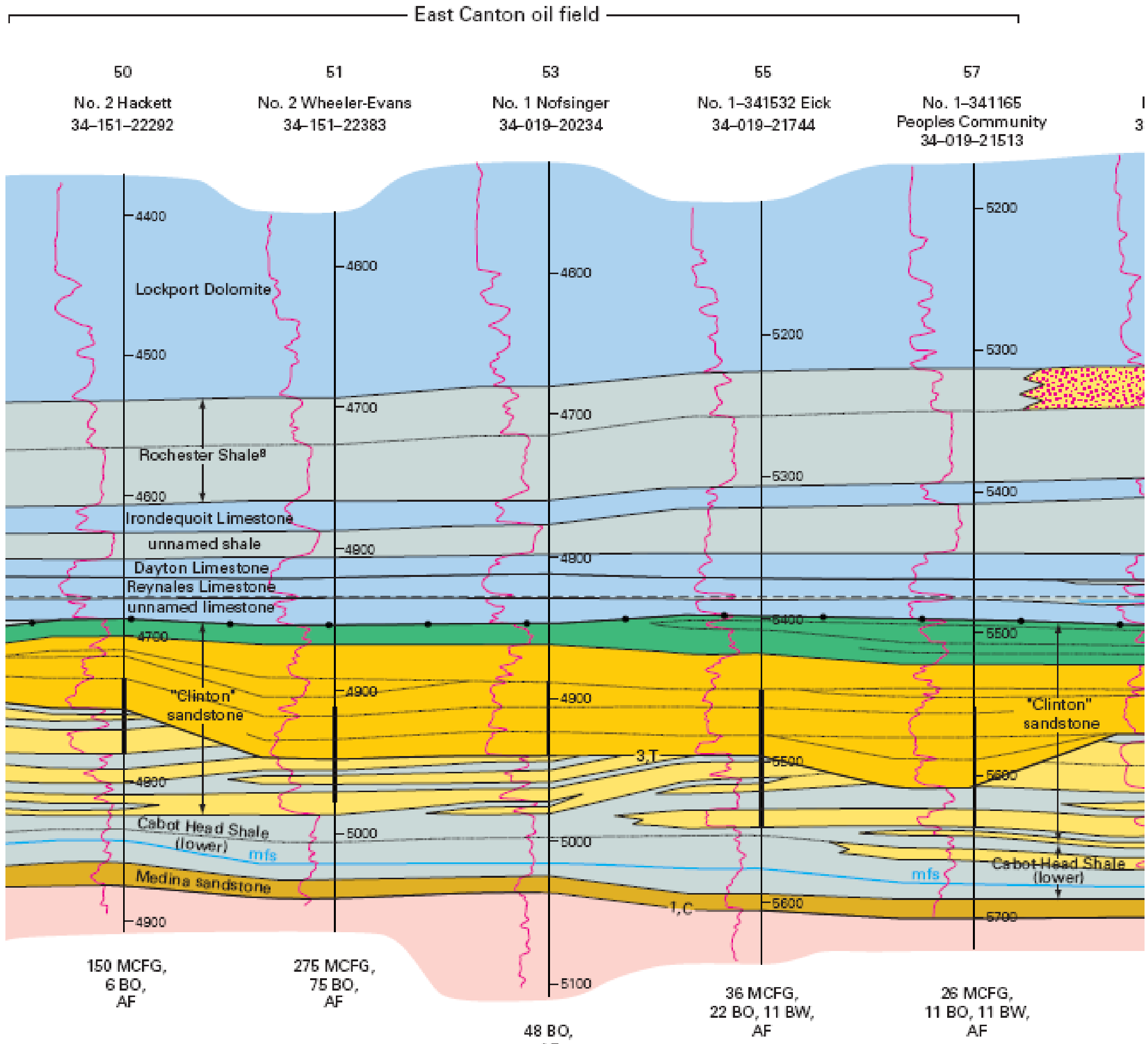


Figure 1A.—Map showing the approximate distribution of natural gas and oil in the Lower Silurian regional oil and gas accumulation of the central Appalachian basin. Also shown is the location of the Lower Silurian Tuscarora Sandstone.

Figure(1): Taken from Ryder (2004), map I-280 sheet 2 of 2.



Robert T. Ryder
2004

Figure (2): East Canton oil field portion of Robert Ryder's Cross section E-E´. Taken from Ryder (2004), map I-280 sheet 1 of 2.

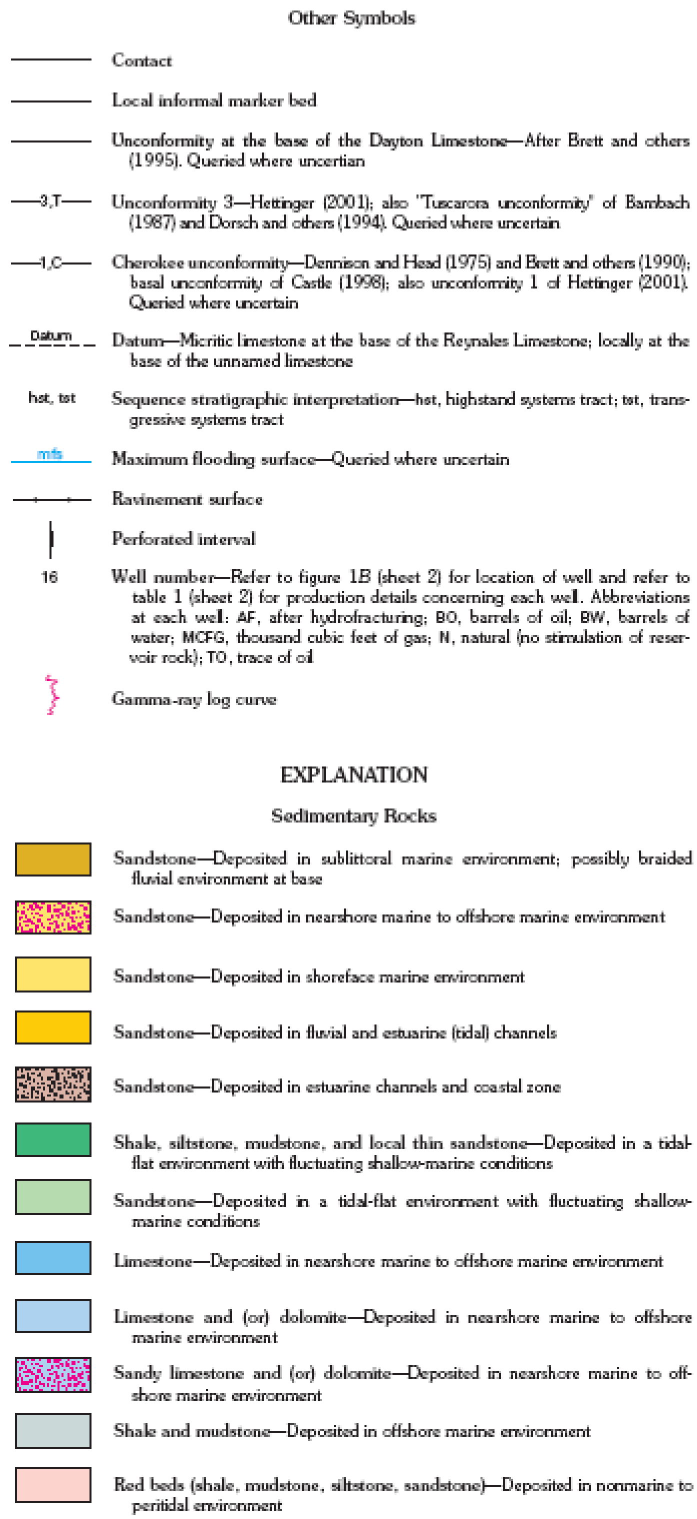


Figure (3): Ryder (2004), Explanation for Cross Section E-E´ from map I-280 sheet 1 of 2.

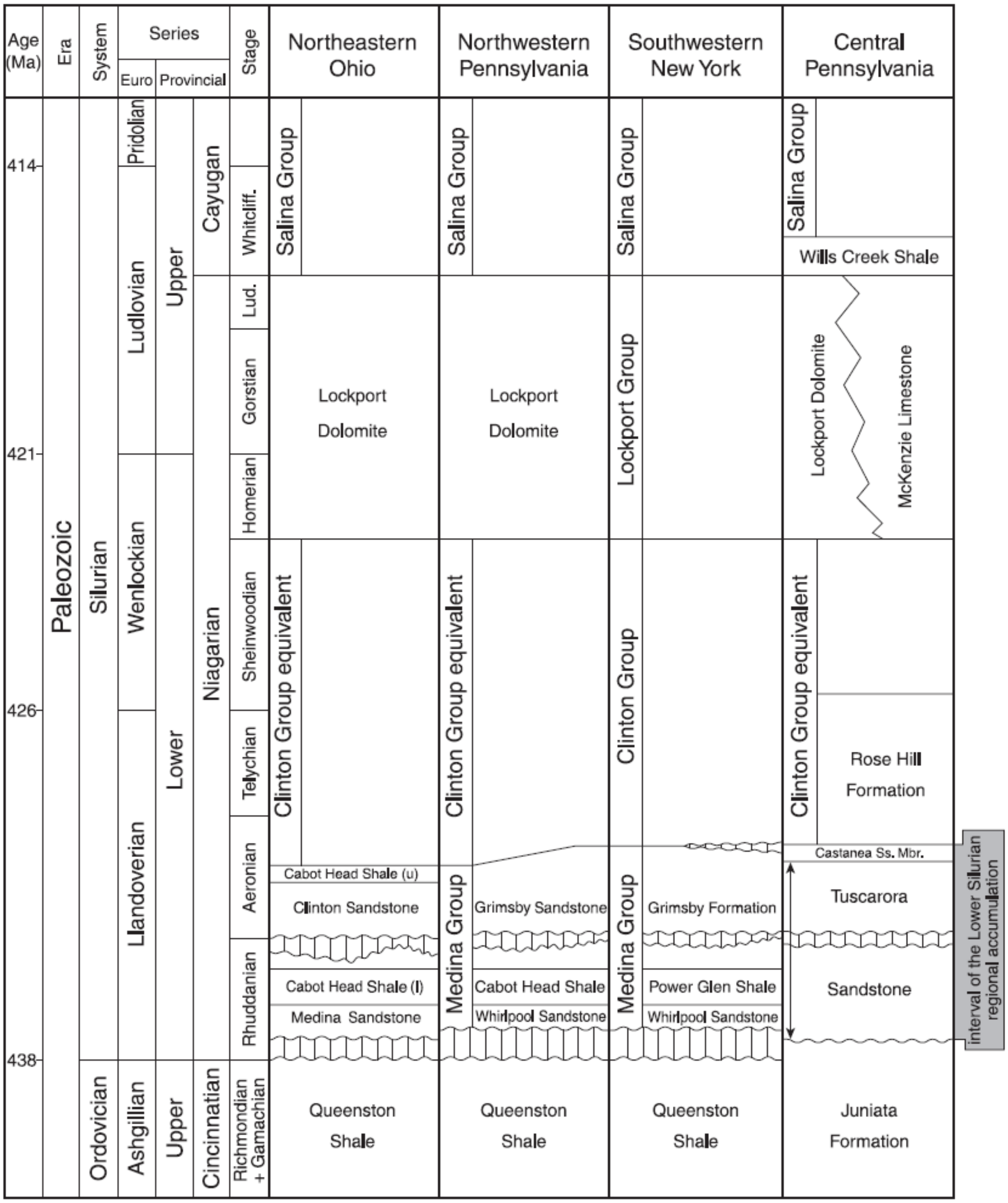


Figure (4): Taken from Ryder and Zagorski (2003) to show regional stratigraphic correlation.

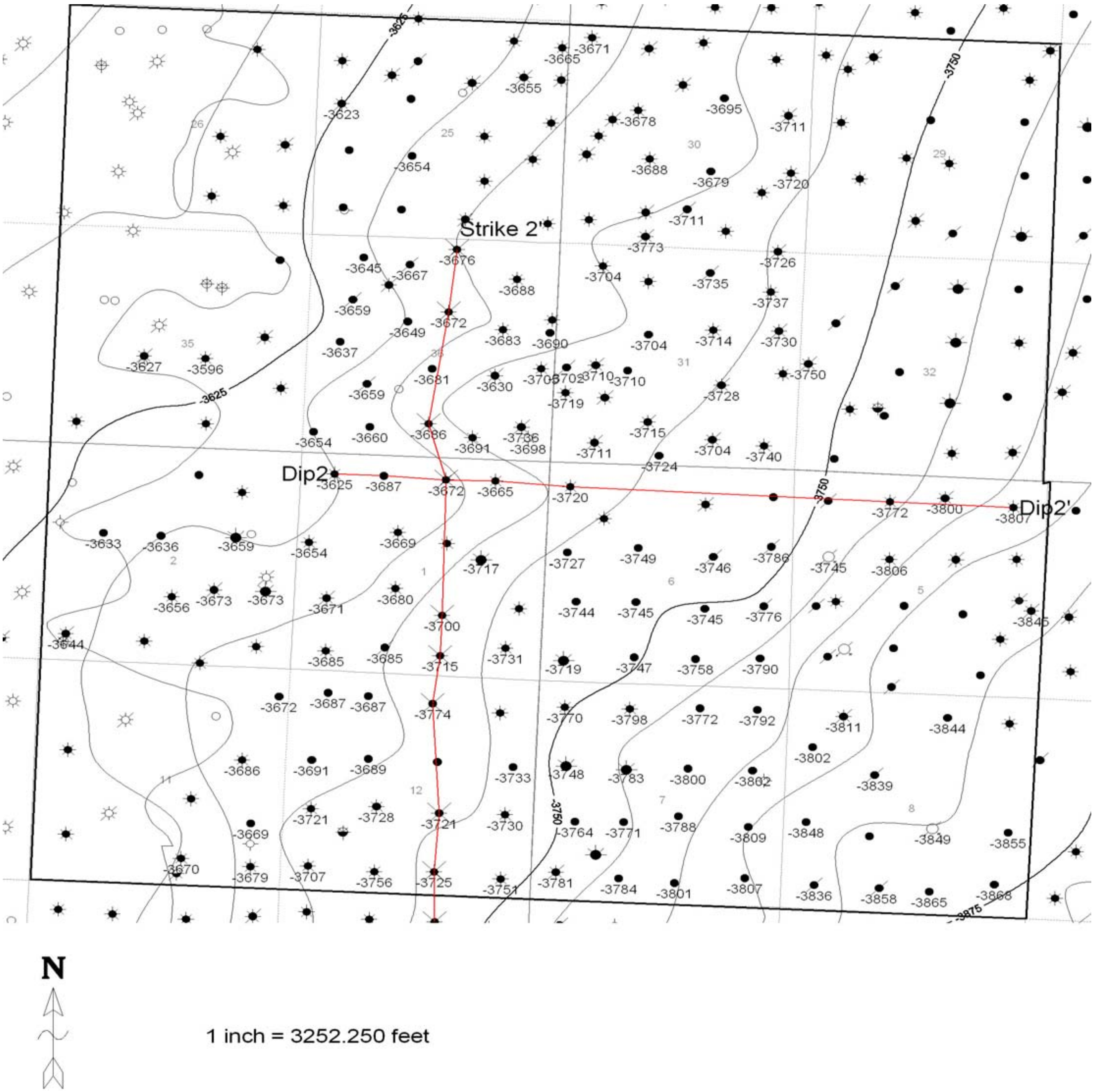


Figure (5): Structure contour map of "Packer Shell" base. This map is a close up of the study area centered on sections of Canton, Osnaburg, Pike, and Sandy Townships of Stark County. Cross section lines Strike 2 and Dip 2 are shown in red. Black starred markers are well locations. Contour Interval = 25 ft.

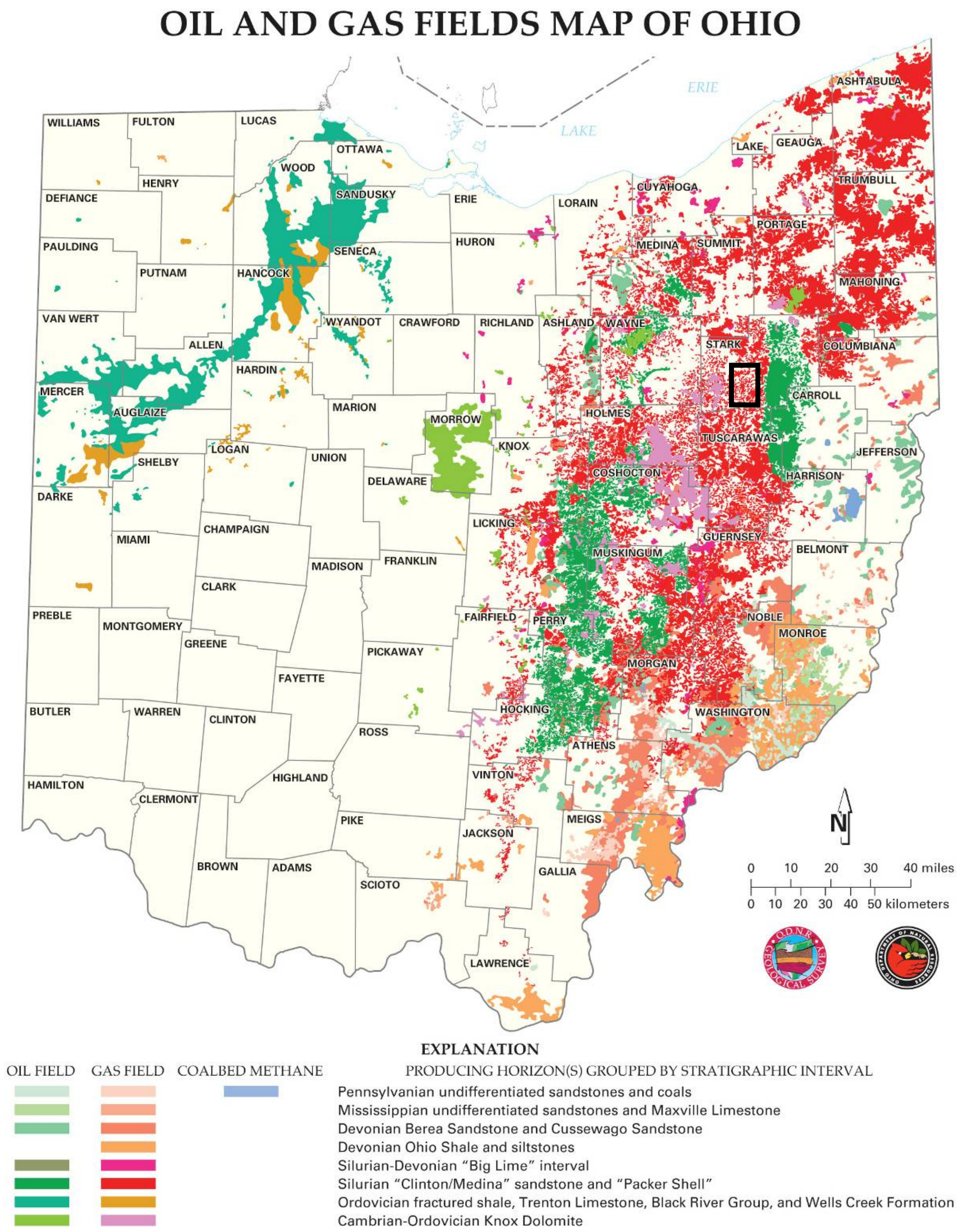


Figure (6): Oil and Gas Field Map of Ohio by The Ohio Geological Survey. Box indicates approximate location of study area in Stark County.

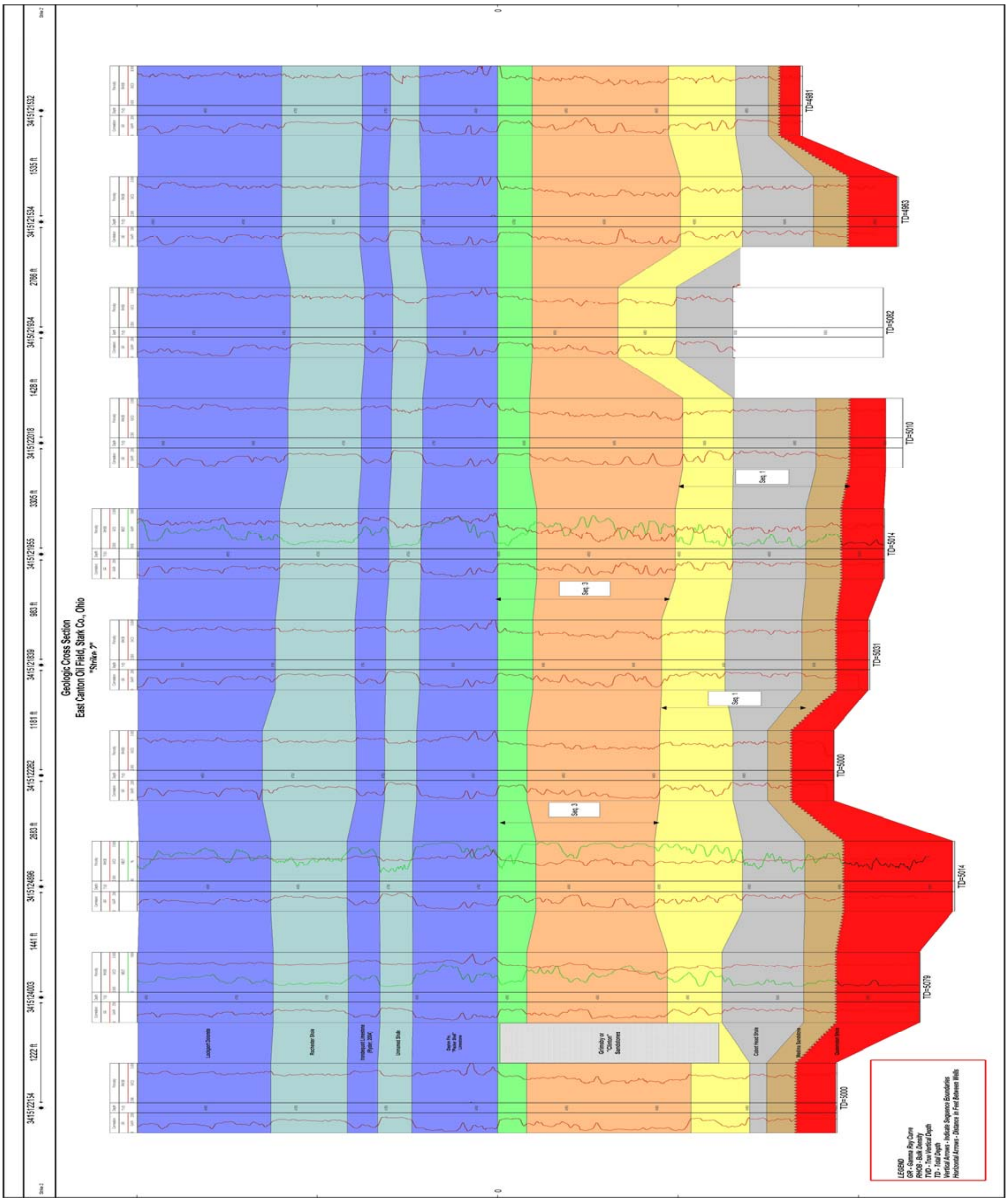


Figure (7): Stratigraphic View of Geologic cross section Strike 2. Note: Cabot Head shale is the lower unit. For explanation of lithologies refer to figure 3.

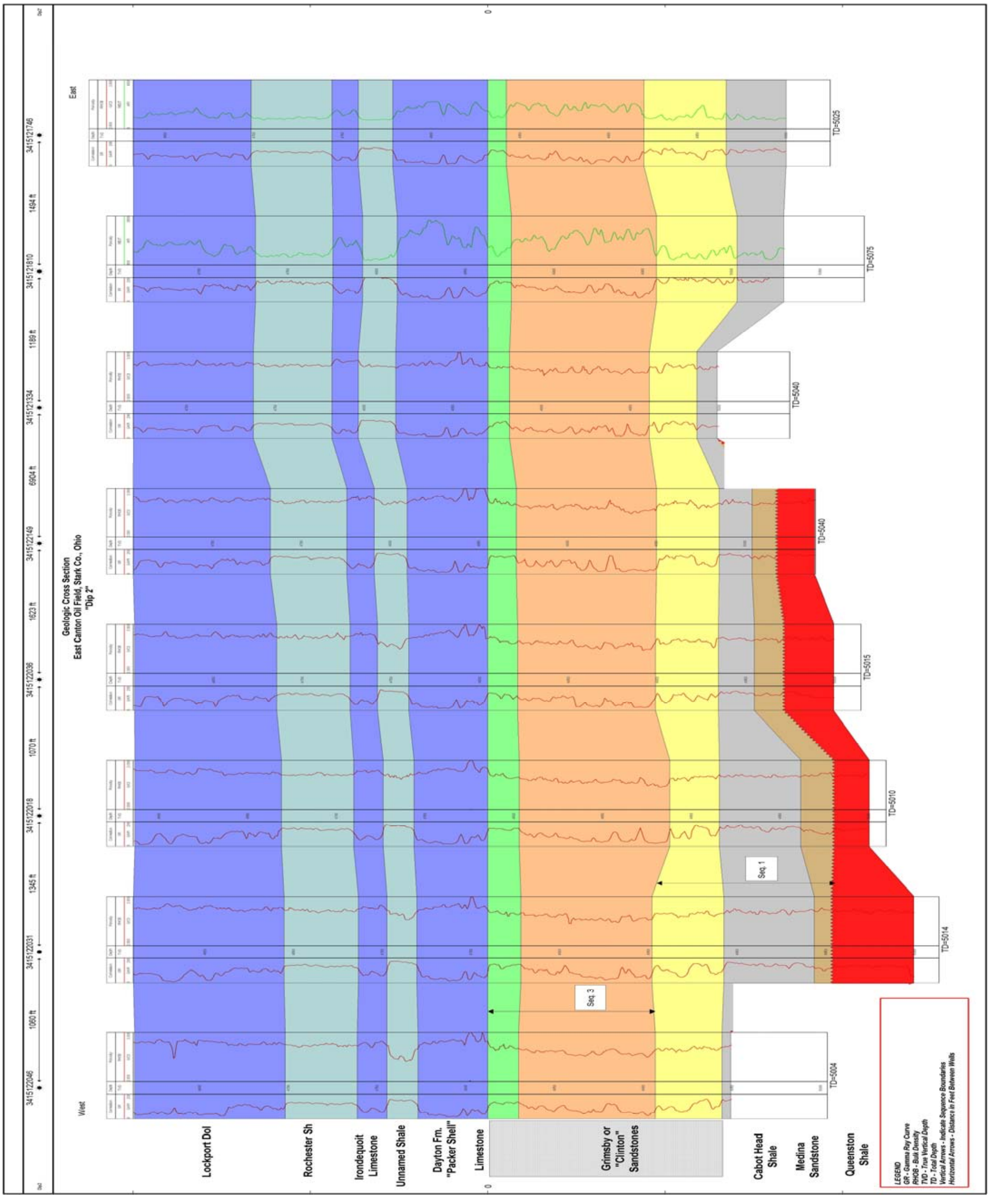


Figure (8): Stratigraphic View of Geologic Cross Section Dip 2. For description of lithologies refer to figure 3. Note: Cabot Head shale is the lower unit.

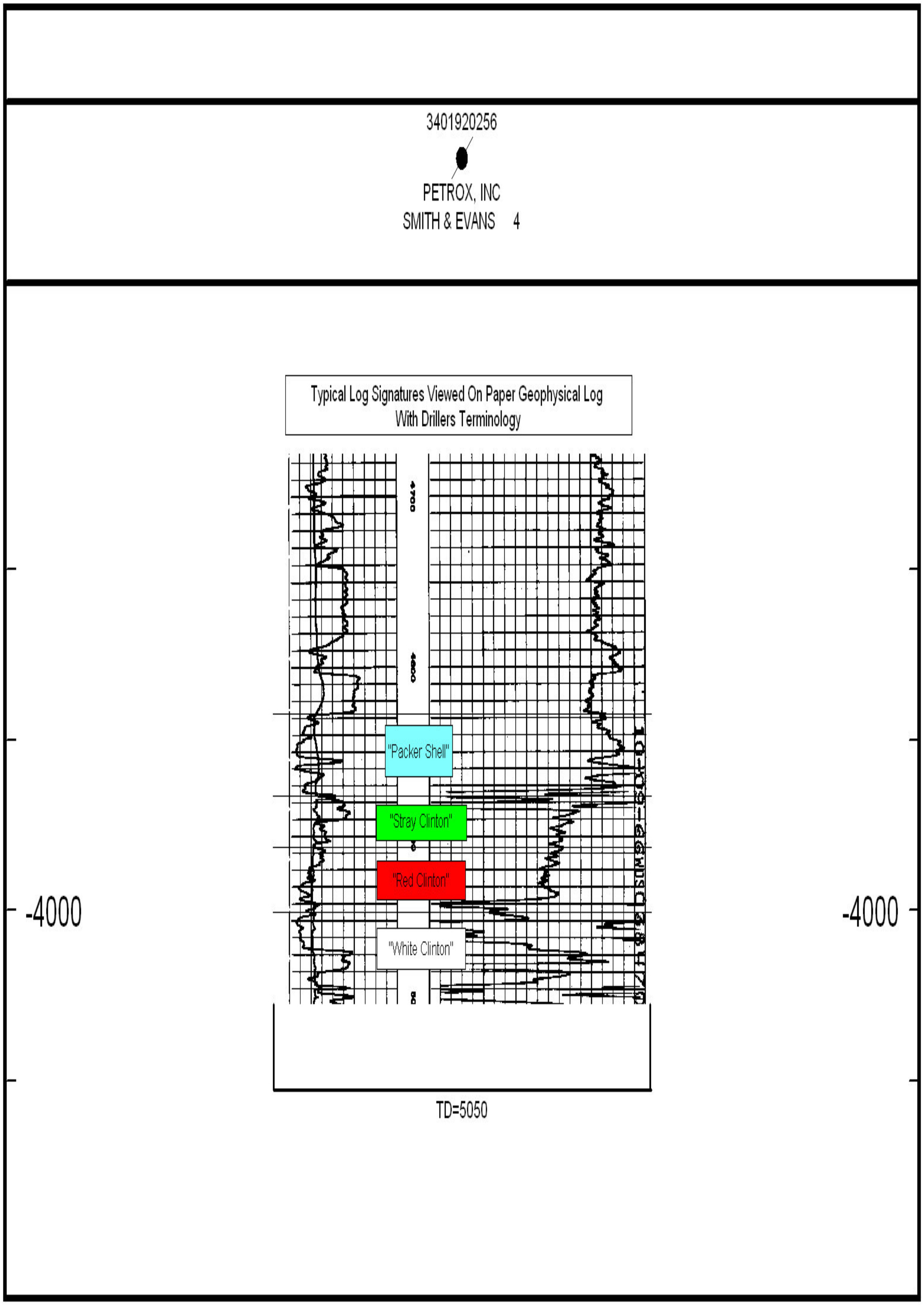


Figure (9): Typical Log Signatures of “Packer Shell”, “Stray Clinton”, “Red Clinton” and “White Clinton” Sandstones. Gamma Ray, Density and Caliper log for the R.P. Smith & S.T. Evans #4 well.

Stray Clinton: Clean to silty fine grained sand, white and gray in color, higher energy environment can be observed by rip up clasts in the upper part of the "Stray Clinton" Core.

Red Clinton: Sand is very fine to fine grained quartz dominant sand, with round to subrounded grain shape, Secondary Mineralization of Hematite gives way to the Red Color of this "Clinton" unit. Structures visible in this unit include parallel to cross bedded laminations.

White Clinton: Very fine to fine grained quartz dominant sandstone with rounded to subrounded grains. Sandstone is white in color with parallel and cross laminations present.

Figure (10): Picture and brief description of "Clinton" Sandstone core taken from R.P. Smith & S.T. Evans #4 well in Caroll County, Ohio, Core (#RE-22) - permit #256.

Sample No.	Depth, ft	Air permeability, md	Porosity, pct1/	Saturation, pct pore vol Oil	Saturation, pct pore vol Water	Oil content, bbl/acre ft	Bulk density, gm/cc1/	Sand grain density gm/cc1/
				Clinton Stray Sand				
2750	4,888.9	2/<0.1	0	0	100.0	0	2.69	2.69
2751	4,890.0	<.1	0.7	0	100.0	0	2.64	2.65
2752	4,891.0	<.1	2.3	0	66.7	0	2.59	2.66
2753	4,892.0	<.1	2.0	0	100.0	0	2.58	2.64
2754	4,893.0	<.1	.4	0	100.0	0	2.60	2.61
2755	4,894.0	<.1	3.6	0	91.7	0	2.56	2.65
2756	4,895.0	<.1	2.1	0	100.0	0	2.59	2.65
2757	4,896.0	<.1	.2	0	100.0	0	2.68	2.68
2758	4,897.0	<.1	2.6	0	100.0	0	2.56	2.63
2759	4,898.0	<.1	0.	-	3/-	-	2.60	2.60
2760	4,899.0	.3	0	-	-	-	2.60	2.60
2761	4,900.0	<.1	.4	0	100.0	0	2.60	2.61
2762	4,901.0	<.1	.2	0	100.0	0	2.63	2.63
Average		<.1	1.1	0	96.2	0	2.61	2.64
				Red Clinton Sand				
2763	4,902.0	<.1	.1	0	100.0	0	2.70	2.70
2764	4,903.0	<.1	.6	0	100.0	0	2.59	2.61
2765	4,904.0	<.1	3.0	0	76.4	0	2.55	2.62
2766	4,905.0	<.1	1.3	0	100.0	0	2.73	2.77
2767	4,906.0	<.1	3.7	0	100.0	0	2.57	2.66
2768	4,907.1	<.1	1.2	0	100.0	0	2.59	2.62
2769	4,908.0	<.1	0	-	-	-	2.67	2.67
2770	4,909.0	<.1	0	-	-	-	2.62	2.62
2771	4,910.0	<.1	.4	0	100.0	0	2.60	2.61
2772	4,911.0	<.1	3.6	0	100.0	0	2.53	2.63
2773	4,912.0	<.1	3.5	0	100.0	0	2.54	2.63
2774	4,913.0	<.1	0	-	-	-	2.74	2.74
2775	4,914.0	<.1	0	-	-	-	2.60	2.60

Figure (11): Core analysis for Stray and Red "Clinton" sandstones by the Belden and Blake Company for core (#RE – 22) - permit #256

Sample No.	Depth, ft	Air permeability, md	Porosity, pct 1/	Saturation, pct pore vol Oil	Water	Oil content, bbl/acre ft	Bulk density, gm/cc 1/	Sand grain density, gm/cc 1/
			First White Clinton Sand					
2801	4,941.0	2/<0.1	3.0	3.3	86.0	8	2.56	2.64
2802	4,942.0	<.1	3.9	5.6	62.2	17	2.54	2.64
2803	4,943.0	<.1	5.9	22.0	23.8	101	2.48	2.64
2804	4,944.0	.2	5.8	20.0	29.4	90	2.49	2.63
2805	4,945.0	3/-	5.0	15.7	34.3	61	2.51	2.64
2806	4,946.2	.1	5.8	7.0	35.5	32	2.50	2.66
2807	4,947.0	.3	5.5	14.7	26.7	63	2.49	2.64
2808	4,948.0	-	6.3	17.3	19.5	85	2.48	2.65
2809	4,949.0	-	5.9	17.0	22.0	78	2.49	2.65
2810	4,950.0	1.7	7.2	-	-	-	2.46	2.65
2811	4,951.0	.5	8.7	14.9	10.6	101	2.41	2.64
2812	4,952.0	.2	4.7	14.6	17.5	53	2.52	2.65
2813	4,953.0	.2	4.4	14.0	23.6	48	2.52	2.64
2814	4,954.0	.1	4.4	4.0	36.9	14	2.53	2.64
2815	4,956.2	.3	6.0	16.7	27.1	78	2.48	2.64
2816	4,957.0	.3	5.7	19.8	19.3	88	2.49	2.64
2817	4,958.0	.1	4.3	15.3	28.1	51	2.52	2.63
2818	4,959.0	.1	4.1	9.4	41.2	30	2.53	2.64
2819	4,960.0	.2	5.1	9.0	29.1	36	2.50	2.64
2820	4,961.0	-	~~5.4~~	18.0	21.7	75	2.50	2.64
2821	4,962.0	.2	4.9	.4	40.0	2	2.51	2.64
2822	4,963.0	.2	5.8	15.0	21.6	68	2.49	2.64
2823	4,964.0	.2	5.5	25.2	14.4	108	2.50	2.65
2824	4,966.4	.1	4.5	4.3	55.4	15	2.52	2.63
te 2825	4,967.0	.2	5.2	19.7	28.6	79	2.50	2.64
2826	4,968.0	2.4	7.4	20.6	15.8	118	2.46	2.65
2827	4,969.0	3.1	~~7.3~~	27.9	20.1	158	2.45	2.65
Average		.5	5.5	14.3	30.4	64	2.50	2.64

Figure (12): Core analysis for first white "Clinton" sandstone by the Belden and Blake Company for core (#RE-22) - permit #256.

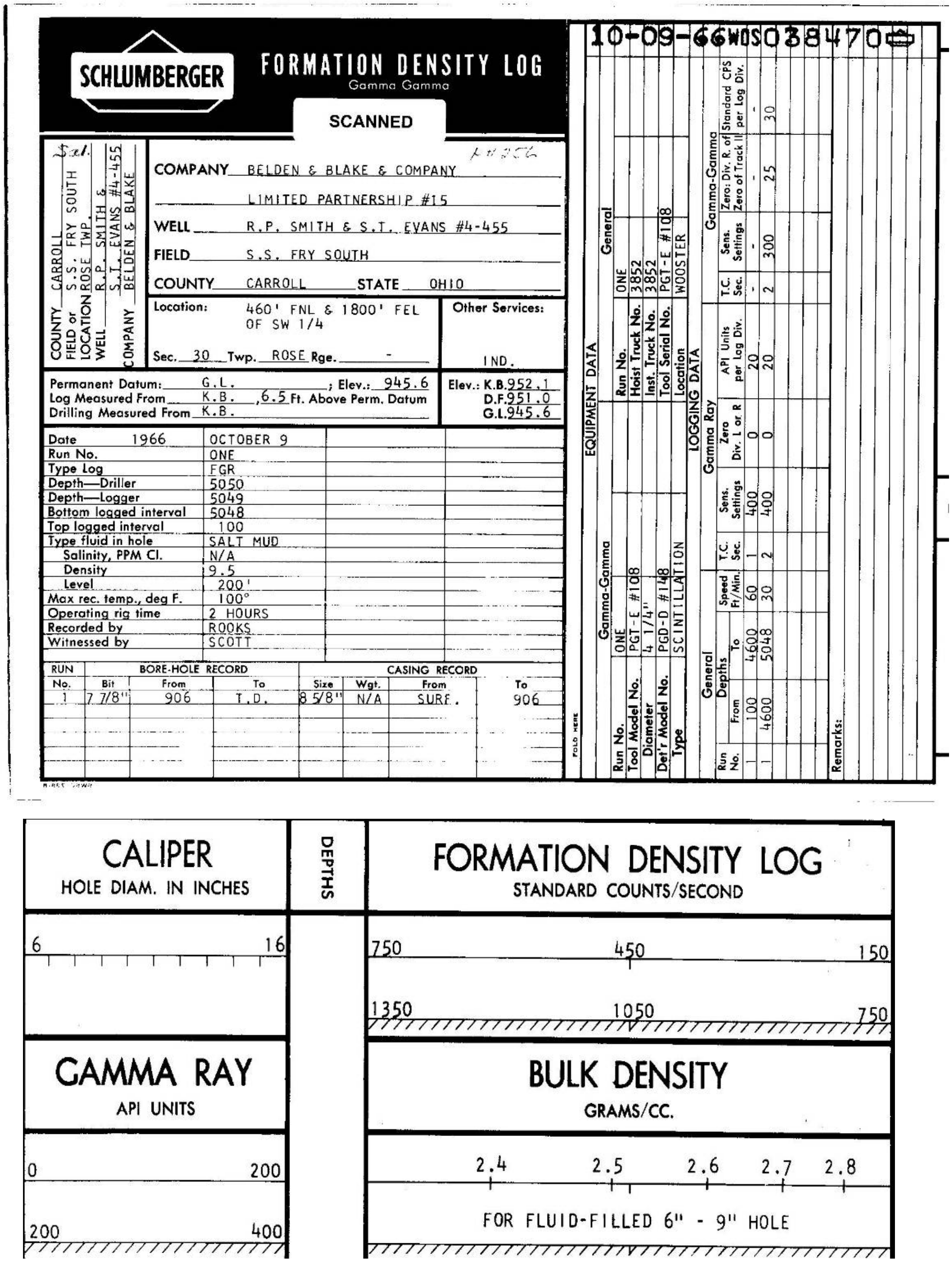


Figure (13): Example of geophysical log header and curve scales with typical units.

```
                              3401920256
~Version Information Block
 VERS.                2.00:    CWLS LOG ASCII STANDARD - VERSION 2.000000
 WRAP.                  NO:    One Line Per Depth Step
#
~Well Information Block
#MNEM.UNIT                    Data                           Information
#----------   ---------------------------------------------   ---------------
 STRT.FT                                          0.0000:     START DEPTH
 STOP.FT                                       5100.0000:     STOP DEPTH
 STEP.FT                                          0.5000:     STEP
 NULL.                                         -999.2500:     NULL VALUE
 COMP.  BELDEN AND BLAKE & COMPANY LIMITED PARTNERSHIP #15:   COMPANY
 WELL.                         RP SMITH& ST EVANS #4-455:     WELL
 FLD .                                      EAST CANTON:      FIELD
 LOC .       460' FNL & 1800' FEL OF SW 1/4 OF SECTION 30:    LOCATION
 LAT .                                      40.716080594:     LATITUDE
 LONG.                                    -81.4073023384:     LONGITUDE
 GDAT.                                             NAD83:     GeoDetic Datum
 TWP .                                              ROSE:     TOWNSHIP
 CNTY.                                           CARROLL:     COUNTY
 STAT.                                                OH:     STATE
 CTRY.                                               USA:     COUNTRY
 SRVC.                                      SCHLUMBERGER:     SERVICE COMPANY
 DATE.                                         10/9/1966:     DATE
 API .                                        3415120256:     API NUMBER
 UWI .                                        3415120256:     UWI NUMBER
 TLD .                                              5048:     TOTAL LOG DEPTH
 RDAT.                                              K.B.:     REFERENCE Datum
 EPD .FT                                           945.6:     Elevation Of REF.
Datum
 FILE.NM       3401920256_GR-C-D_SCH_100_5048_N_100_TH45:     FILE NAME
 WSTA.                                               LOC:     Well status
#
~Curve Information Block
#MNEM.UNIT       API CODE      Curve Description
#----------    -------------   -------------------
 DEPT.FT                    :   Depth in Feet
 RHOB.CPS      42 350 01 01:   Bulk Density
 GR   .GAPI    35 310 01 01:   Gamma Ray
 NEUT.N        35 330 30 01:   Neutrons
#
~Parameter Information Block
#MNEM.UNIT            Value               Description
#----------    --------------------    -------------------
 RUN .                        ONE:     Run Number
 PDAT.                           :     Permanent Datum
 EPD .FT                   0.0000:     Elevation Of Perm. Datum
 WSTA.                        LOC:
 E   .FT                   0.0000:     E (Stretch Coefficient Of The Cable)
 TD  .FT                5100.0000:     Total Depth
#
~Other Information Block
<DescLogPlotStart>   NEURALOG PLOT DEFINITION
PLOTDEFVERSION: 3
LASFILE: C:\neuraviewTE\projects\sample\LAS\las\3401920256_GR-C-D_BW_100_5048_N
DEPTHSCALE: 239.999996
RESOLUTION: 200
DEPTHLABELFREQ: 100.000000
HEAVYGRIDFREQ: 100.000000
MEDIUMGRIDFREQ: 50.000000
LIGHTGRIDFREQ: 10.000000
#
#   TRACK 1
```

Figure (14): Example of LAS text file header with curve information and parameters included.

```
                        3401920256
#
STARTTRACK:
 LEFTX: 0.500000 inch
 RIGHTX: 3.000000 inch
 SCALETYPE: Linear
 NUMCHARTDIVISIONS: 10
CURVE: RHOB  750.000000 150.000000 (0,0,255)     Solid      2   Y
BACKUP: 1350.000000 750.000000 (0,0,255)    Solid      2
CURVE: GR    0.000000   150.000000 (255,0,0)     Solid      2   N
CURVE: NEUT  1017.009784 1805.564871 (0,0,0)      Solid      2   N
ENDTRACK:
<DescLogPlotEnd>
~A DEPTH     RHOB              GR               NEUT
      0.000 -999.25000000    50.10060362     1329.50000000
      0.500 -999.25000000    48.08853119     1329.50000000
      1.000 -999.25000000    44.86921529     1345.50000000
      1.500 -999.25000000    39.86330482     1363.66290107
      2.000 -999.25000000    36.03037605     1377.41146867
      2.500 -999.25000000    34.41719389     1406.26977866
      3.000 -999.25000000    33.94222888     1423.80305716
      3.500 -999.25000000    31.51702900     1435.37342683
      4.000 -999.25000000    30.33924845     1448.18247847
      4.500 -999.25000000    29.97280171     1484.42186748
      5.000 -999.25000000    29.67158501     1503.48424639
      5.500 -999.25000000    29.56853005     1525.56066424
      6.000 -999.25000000    29.57849314     1542.98655056
      6.500 -999.25000000    29.54564980     1576.51205065
      7.000 -999.25000000    29.41134894     1631.15667302
      7.500 -999.25000000    32.20659124     1634.05691236
      8.000 -999.25000000    32.89634233     1643.07866784
      8.500 -999.25000000    37.08792372     1647.32879022
      9.000 -999.25000000    39.81765900     1628.50599274
      9.500 -999.25000000    40.42109462     1616.03146296
     10.000 -999.25000000    47.53060891     1558.61977609
     10.500 -999.25000000    48.42937482     1458.13372170
     11.000 -999.25000000    49.94796945     1464.26429441
     11.500 -999.25000000    48.48031792     1197.81946525
     12.000 -999.25000000    49.99446600     1090.76259863
     12.500 -999.25000000    50.97201826     1085.20000000
     13.000 -999.25000000    49.69193852     1079.50000000
     13.500 -999.25000000    48.53304967     1074.50000000
     14.000 -999.25000000    48.15352800     1070.00886465
     14.500 -999.25000000    47.13554177     1072.20146167
     15.000 -999.25000000    46.55193685     1074.74505369
     15.500 -999.25000000    44.81679219     1071.70606327
     16.000 -999.25000000    45.66255892     1069.37221073
     16.500 -999.25000000    45.31882354     1068.65854481
     17.000 -999.25000000    43.54908881     1069.14408217
     17.500 -999.25000000    45.43226515     1072.69254496
     18.000 -999.25000000    43.15133832     1073.78459766
     18.500 -999.25000000    41.99457111     1068.78292219
     19.000 -999.25000000    43.55362914     1057.94724288
     19.500 -999.25000000    40.80446916     1054.13891929
     20.000 -999.25000000    41.52188699     1053.37478696
     20.500 -999.25000000    41.98322129     1055.18625095
     21.000 -999.25000000    43.10938466     1055.75798090
     21.500 -999.25000000    44.53144540     1049.80190832
     22.000 -999.25000000    44.73789928     1050.58555513
     22.500 -999.25000000    45.75045332     1049.50565138
     23.000 -999.25000000    47.10446437     1049.25461384
     23.500 -999.25000000    48.51810749     1048.51442480
     24.000 -999.25000000    48.21455457     1048.58689730
     24.500 -999.25000000    47.26611141     1052.61501003
```

Figure (15): Example of vector read out for Bulk Density (RHOB), Gamma Ray (GR), and Neutron (NEUT) curves. Note: Bulk Density reads out negative values until curve interval is reached.

References

Blomberg John, 1996, Where might enhanced oil recovery (EOR) methods be successful in Ohio in the Future? Canton Symposium IV: Fourth annual technical symposium, October, 1996, Ohio Geological Society, p. 10-24.

Cano Petroleum, 2008, Producing Oil & Gas In the U.S.A., (Waterflooding Video and Tutorial), http://www.canopetro.com.

Carl, J.F., 1890, Seventh report on the oil and gas fields of western Pennsylvania: Second Geological Survey of Pennsylvania, p. 12-13.

Castle, J.W., 1998, Regional sedimentology and stratal surfaces of a Lower Silurian clastic wedge in the Appalachian foreland basin: Journal of Sedimentary Research, v. 68, no. 6, p. 1201-1211.

Castle, J.W., and Byrnes, A.P., 2005, Petrophysics of Lower Silurian sandstones and integration with the tectonic-stratigraphic framework, Appalachian basin, United States: American Association of Petroleum Geologists Bulletin, v. 89, no. 1, p 41-60.

Crangle, R.D, Log ASCII Standard (LAS) files for geophysical wireline well logs and their application to geologic cross sections through the Central Appalachian Basin, Open File Report, U.S.G.S., 2007 of 2007-1142: 14 pp.

Dennison, J.M., and Head, J.W., 1975, Sea level variations interpreted from the Appalachian basin Silurian and Devonian: American Journal of Science, v. 275, p. 1089-1120.

Hettinger, R.D., 2001, Subsurface correlations and sequence stratigraphic interpretations of Lower Silurian strata in the Appalachian basin of northeast Ohio, southwest New York, and northwest Pennsylvania: United States Geological Survey Geologic Investigations Series I-274.

IPCC, 2001: Climate Change 2001: Mitigation. Contribution of the Working Group III to the Third Assessment Report of the Intergovernmental Panel on Climate Change (Houghton, J.T. et al., eds), Cambridge and New York 2001.

Janssens, A., 1977, The Silurian rocks in the subsurface of northwestern Ohio: Ohio Geologic Survey Report, Inv. 24, p. 41-53.

Keltch, B., 1985, Why Use Geology for Clinton Exploration? (Examples and reasons from Guernsey county, Ohio), in The new Clinton collection, 1985, Ohio Geological Society, p. 19-42.

Kleffner, M.A., 1985, Conodont biostratigraphy of the stray “Clinton” and “Packer Shell” (Silurian, Ohio subsurface) and its bearing on correlation, in The new Clinton collection; 1985: Columbus, Ohio Geological Society, p. 221–230.

Knight, W.V., 1969, Historical and economic geology of Lower Silurian Clinton Sandstone of northeastern Ohio: American Association of Petroleum Geologists Bulletin, v. 53, p. 1421-1452.

Laughrey, C.D., 1984, Petrology and reservoir characteristics of the Lower Silurian Medina Group sandstones, Athens and Geneva fi elds, Crawford County, Pennsylvania: Pennsylvania Geological Survey, 4th ser., Mineral Resource Report 85, 126 p.

Lewis, J.O., 1917, Smith-Dunn or Marietta compressed-air process: U.S. Bureau of Mines Bulletin 148, p. 36-91 (reprinted in Ohio Division of Geological Survey Information Circular 8, 1951, p. 87-104).

Laughrey, C.D., and Harper, J. A., 1986, Comparisons of Upper Devonian and Lower Silurian tight formations in Pennsylvania —geological and engineering characteristics, *in* Spencer, C.W., and Mast, R.F., eds., Geology of tight gas reservoirs: American Association of Petroleum Geologists Studies in Geology 24, p. 9-43.

McCormac, M. P., Mychkovsky, G. O., Opritza, S. T., Riley, R. A., Wolfe, M. E., Larsen, G. E., and Baranoski, M. T., 1996, Play Scm: Lower Silurian Cataract/Medina Group (“Clinton”) sandstone play, p. 156-163, *in* Roen, J. B., and Walker, B. J., eds., The atlas of major Appalachian gas plays: West Virginia Geological and Economic Survey Publication V-25, 201 p.

Middleton, G.V., Rutka, M., and Salas, C.J., 1987, Depositional environments in the Whirlpool Sandstone Member of the Medina Group, in Duke, W.L., ed., Sedimentology, stratigraphy, and ichnology of the Lower Silurian Medina Formation in New York and Ontario: Society of Economic Paleontologists and Mineralogists, Eastern Section, 1987 annual field trip guidebook, p. 1–15.

O'Donnell, J.P., 1940, Ohio's first water-flood project promises moderate success: Oil and Gas Journal, Vol. 38, no. 49, p.42-43.

Orton, E., 1888, The geology of Ohio considered in its relation to petroleum and natural gas: Ohio Geological Survey, v. 16, p.1-59.

Overbey, W.K., Jr., and Henniger, B.R., 1971, History, development, and geology of oil fields in Hocking and Perry Counties, Ohio: American Association of Petroleum Geologists Bulletin, v. 55, no. 2, p. 183–203.

Ryder, R.T., and Zagorski, W.A., 2003, Nature, origin, and production characteristics of the Lower Silurian regional oil and gas accumulation, central Appalachian basin, United States: American Association of Petroleum Geologists Bulletin, v. 87, no. 5, p. 847–872.

Ryder, R.T., 2004, Stratigraphic framework and depositional sequences in the Lower Silurian regional oil and gas accumulation, Appalachian basin; From Ashland County, Ohio, through Southwestern Pennsylvania, to Preston County, West Virginia: U.S. Geological Survey Miscellaneous Investigations Series Map I–2810, 2 sheets, 8-p. text.

Schrider, L.A., Watts, R.J., and Wasson, J.A. 1969, East Canton Oilfield Waterflood Evaluation (Prepared for Meeting of the Society of Petroleum Engineers, Nov. 6-7, 1969, Columbus, Ohio). Society of Petroleum Engineers, SPE 2764.

Schrider, L.A., Watta, R.J., and Wasson, J.A., 1970, An evaluation of the East Canton oil field waterflood: Journal of PetroleumTechnology, v. 22, p. 1371-1378.

Sitler, G.F., Jr., 1985, East Canton-Magnolia oil field (Presented at the winter meeting of the Ohio Oil and Gas Association, March 7, 1969, Columbus, Ohio), in Clinton sandstone papers presented at the Ohio Oil and Gas Association winter meetings, 1961 to 1987; Abridged reprint—1985: Columbus, Ohio, Ohio Geological Society, p. 41–51.

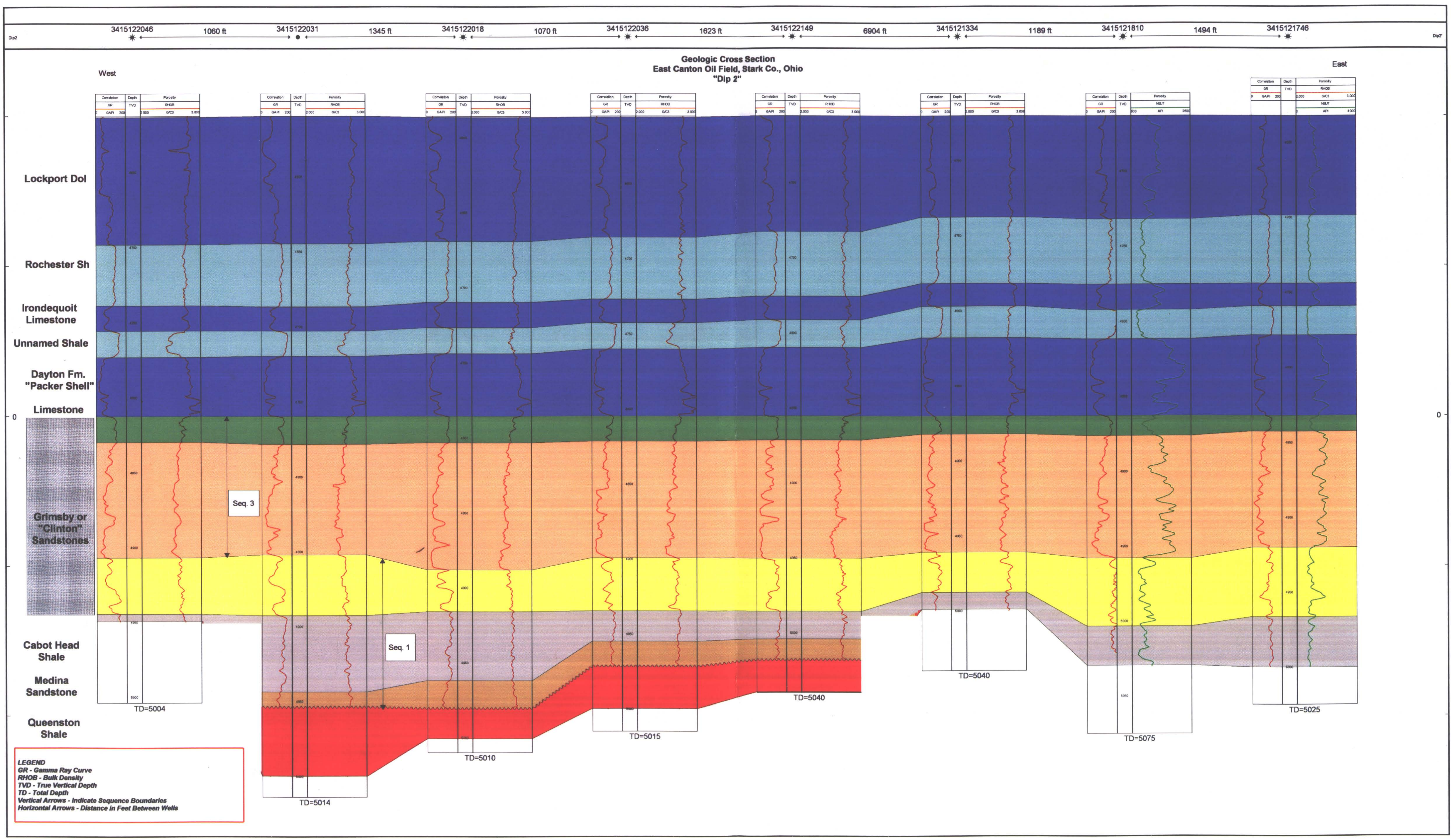
Watts, R.J, Schrider, L.A., Craig, J.G., 1970, Reservoir and Production Characteristics of the Clinton Sand, East Canton Oilfield, in Clinton Sandstone Papers, Abridged Reprint, 1985, Ohio Geological Society, p. 55-77.

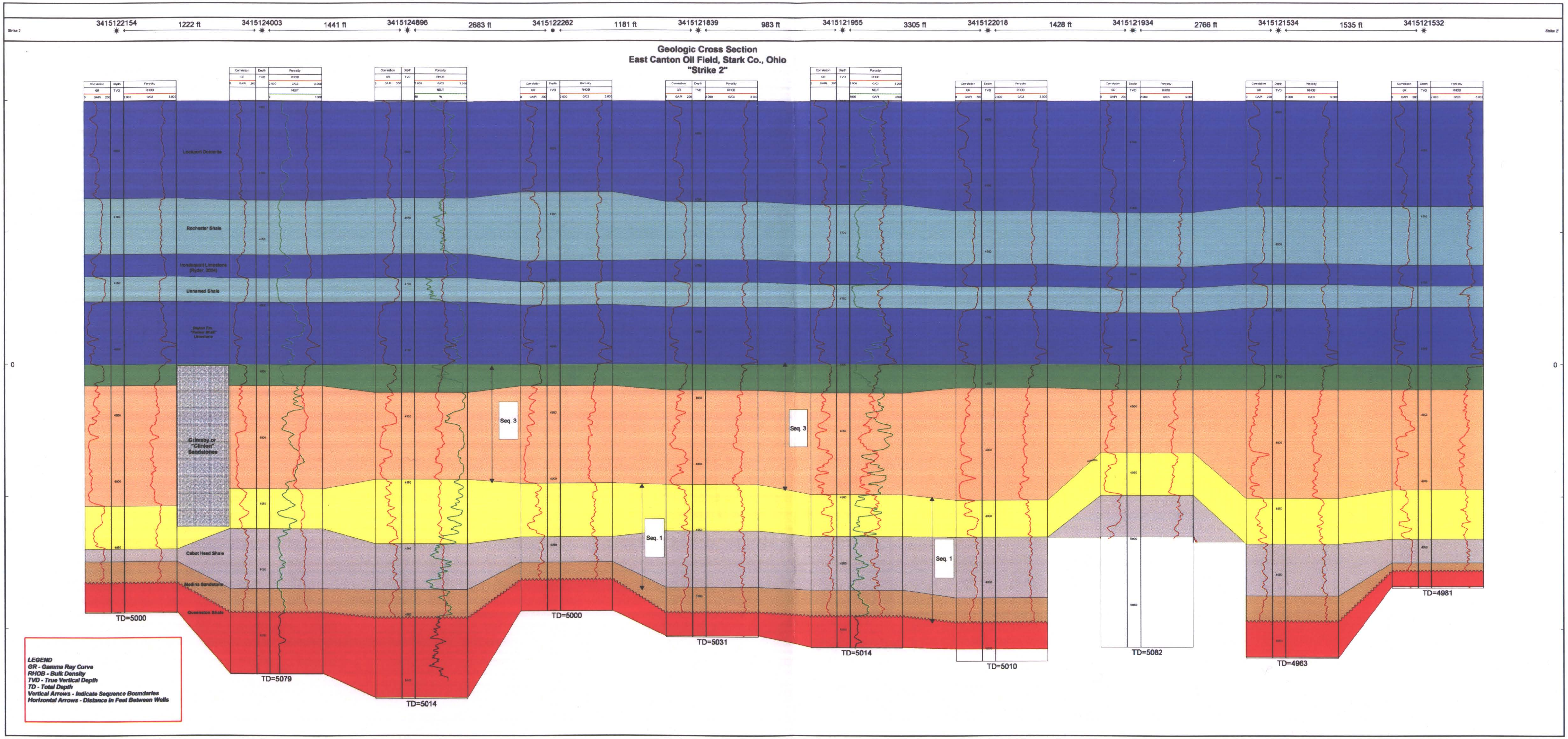
Wolfe, M.E., 1996, A Review of Enhanced Oil Recovery in Ohio with a focus on the historical low pressure air injection in the Chesterhill Field, Morgan County, Ohio, in Canton Symposium IV: Fourth annual technical symposium, October, 1996, Ohio Geological Sociey, p. 195-199.

Wonziak, D.A., Wing, J.L., Schrider, L.A., 1997, Infill Reserve Growth Resulting From Gas Huff-n-Puff and Infill Drilling-A Case History, (Prepared for SPE regional meeting in Lexington, Kentucky), Society of Petroleum Engineers, SPE 39214, p. 23-36.

Schlumberger, 1969, Log Interpretation Principals Document, and all References Credited within apply to citation for Schlumberger in this work.

TORIS, 1996: This is the Tertiary Oil Recovery Information System database by the Department of Energy, This was completed for Ohio in 1996.


Dip2
3415122046
1060 ft
3415122031
1345 ft
3415122018
1070 ft
3415122036
1623 ft
3415122149
6904 ft
3415121334
1189 ft
3415121810
1494 ft
3415121746
Dip2'
Geologic Cross Section
East Canton Oil Field, Stark Co., Ohio
"Dip 2"
West
East
Lockport Dol
Rochester Sh
Irondequoit Limestone
Unnamed Shale
Dayton Fm. "Packer Shell" Limestone
Grimsby or "Clinton" Sandstones
Cabot Head Shale
Medina Sandstone
Queenston Shale
Seq. 3
Seq. 1
TD=5004
TD=5014
TD=5010
TD=5015
TD=5040
TD=5040
TD=5075
TD=5025
LEGEND
GR - Gamma Ray Curve
RHOB - Bulk Density
TVD - True Vertical Depth
TD - Total Depth
Vertical Arrows - Indicate Sequence Boundaries
Horizontal Arrows - Distance in Feet Between Wells



Strike 2
3415122154
1222 ft
3415124003
1441 ft
3415124896
2683 ft
3415122262
1181 ft
3415121839
983 ft
3415121955
3305 ft
3415122018
1428 ft
3415121934
2766 ft
3415121534
1535 ft
3415121532
Strike 2'
Geologic Cross Section
East Canton Oil Field, Stark Co., Ohio
"Strike 2"
Correlation
GR
Depth
TVD
Porosity
RHOB
NEUT
Lockport Dolomite
Rochester Shale
Irondequoit Limestone (Ryder, 2004)
Unnamed Shale
Dayton Fm. "Packer Shell" Limestone
Grimsby or "Clinton" Sandstones
Cabot Head Shale
Medina Sandstone
Queenston Shale
Seq. 3
Seq. 1
Seq. 3
Seq. 1
0
0
TD=5000
TD=5079
TD=5014
TD=5000
TD=5031
TD=5014
TD=5010
TD=5082
TD=4963
TD=4981
LEGEND
GR - Gamma Ray Curve
RHOB - Bulk Density
TVD - True Vertical Depth
TD - Total Depth
Vertical Arrows - Indicate Sequence Boundaries
Horizontal Arrows - Distance in Feet Between Wells